AuCuAl Shape Memory Alloys for Use in Opto-Mechanical Nanoactuators

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy (Science) at the University of Technology, Sydney

by

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Certificate of Authorship / Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis

Signed:

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Abstract

Shape memory alloys (SMAs) are a remarkable family of metallic materials that have the ability to return to their initial state and shape after being deformed. The key attribute that candidate alloys must possess is the existence of a reversible martensitic phase transformation. The most commonly used SMA, NiTi or 'Nitinol', has been proposed for a number of practical and theoretical applications [1-4], however a 100 nm lower limit has been found when producing thin films of this material for nanoscale applications. It has been shown that TiNi films thinner than this lose their shape memory effect due to oxide formation [5]. In the present work I explore whether variations of the $Au_7Cu_5Al_4$ SMA could be used as an alternate material for nanoscale SMA applications due to the resistance of $Au_7Cu_5Al_4$ to both aging [6] and oxidation [7]. A bonus is that the high Au content of this alloy may allow it to support a surface plasmon resonance in the visible part of the electromagnetic spectrum.

My project involved the investigation of both bulk and thin-film samples. A range of techniques were used to examine the properties of both the bulk and thin-film alloys including SEM, TEM, EDS, SIMS, powder diffraction (X-ray and neutron), thermal analysis, electrical resistance and spectrophotometry. Various types of mathematical modelling were then used to interpret the results as well as to simulate the operation of hypothetical devices made with this alloy.

Bulk AuCuAl SMAs with Al content varying along the Au 85 wt.% Au line of the AuCuAl ternary diagram were produced and their microstructures, physical properties and phase transformations studied. The extent to which the prototypical $Au_7Cu_5Al_4$ alloy resisted aging was investigated and the mechanisms that lead to some small changes in the transformation temperature under particular circumstances were considered. Whilst these alloys are very resistant to aging at high temperatures, aging below approximately 140°C in the austenite phase field results in a surprising and significant drop in the subsequent martensite-to-austenite transformation temperature.

Nanoscale films of AuCuAl with similar compositions to those of the bulk alloys were then synthesised. The phase transformation characteristics in these samples were also determined and found to be sensitive to the Al content and deposition conditions. The sub-100 nm-thick films were produced following the same compositional trend as the bulk ternary samples, producing a sequence of α-, β- and γ-structured films as the Al content was systematically increased. It is shown that, when deposited under the right conditions and with the correct compositions, AuCuAl films could be produced with the ability to undergo a reversible austenite/martensite phase transformation. Reflection and transmission spectra of these films were measured and used to calculate their dielectric function (complex refractive index). These data were in turn used to model the localised surface plasmon resonances in hypothetical, opto-mechanical nano-actuators made from $Au_7Cu_5Al_4$. The calculations predict that the extinction of light of a wavelength of 740 nm could be modulated by a factor of 26 times by a suitably designed, SMA actuator.

This project has paved the way for the possible future fabrication and testing of new opto-mechanical devices based on these principles.